# Learning on the job through collaborative learning: analysing the appropriation of BIM knowledge in micro-enterprise architectural design companies

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**Abstract**. The lack of Building Information Modelling (BIM) knowledge appropriation by Architectural, Engineering, Construction and Operation (AECO) professionals is often considered one of the main obstacles to successful BIM implementation. Although barriers to implementation have been substantially investigated, a literature review on knowledge appropriation revealed that this area is poorly investigated and biased towards small and medium construction companies. The review also shows that no published research has addressed micro-enterprise design firms, despite these representing approximately 90% of the firms in the AECO sector. In this context, this research investigates whether collaborative learning can be a teaching and learning strategy for appropriating BIM knowledge in architectural design micro-enterprises. The Zone of Proximal Development concept and the Collaborative Learning method were the theoretical lenses to study BIM knowledge appropriation. The research method involved documental analysis of four years of data from a micro-enterprise. The data was classified into vertical collaboration, diagonal collaboration; horizontal collaboration; and individual action. Results show a progressive development of the professionals' (BIM knowledge) autonomy, as they gradually moved from individual action and vertical collaboration relationships to diagonal and horizontal collaboration actions. The evidence indicates that teaching and learning strategies can contribute to the appropriation of BIM knowledge in the context of micro and small companies.

## 1. Introduction

Building Information Modelling (BIM) is considered a paradigm for gaining efficiency and value for the Architectural, Engineering, Construction and Operation (AECO) sector. However, there is an adoption process slower than expected. Evidence points out that the existence of barriers to BIM implementation is concentrated in customers who do not understand and therefore do not clearly demand

what to get with the use of BIM [1], in the absence of appropriate technology for business management [2], on the need for new skills in BIM [3], among other minor factors. Authors who addressed different adoption aspects proposed in their discussions some general categories related to the main problems that restrain BIM adoption [2,4]. Alreshidi *et al.* [2] grouped the barriers to adopting BIM into socio-organisational, financial, technical, contractual, and legal categories. The socio-organisational category involves relationships between people, resistance to change or insecurity with new technologies, and a lack of BIM understanding and training. These studies indicate that a critical point for changing processes, technologies and policies is the acceptance and training of the people involved. Oesterreich and Teuteberg [5] presented a socio-technical view of the AECO sector, which recognised barriers related to structure, people, technology, and activities. The authors proposed a series of actions for decision-making aimed at overcoming these barriers, including the training of people, with demands for training and higher education focused not only on software.

In this context, this research investigates whether collaborative learning can be a teaching and learning strategy for utilising BIM knowledge in an architectural design micro-enterprise. Both Zone of Proximal Development and Collaborative Learning principles formed the theoretical foundation to study BIM knowledge appropriation through longitudinal content analysis.

## 2. Literature Review and Theoretical Foundation

### *2.1. Non-Formal Education in BIM*

Education can be classified as Formal and Non-formal [6]. In this context, Formal education is related to institutionalised school processes under State regulation. Non-formal education is related to spaces where there is an intentional teaching-learning process, like formal education, but without State validation or certification. In a review of the literature on BIM between 2015-2020, out of a total of 143 references, 25 referred to BIM education, only three studies were identified that mentioned non-formal education [7,8,9]. Boulton and Lamb [8] and UK BIM Framework [9] are reports from institutional diagnoses with a profile to support training people for digitalisation in the UK. Rodriguez *et al.* [7] does not explicitly specify the term non-formal education, but the description of training fits into the definitions of non-formal education.

This formation gap points out the relevance of further studies that address non-formal education in spaces such as companies, where the demand for innovation depends on people's training. In the case of the move to BIM, the mentioned barriers indicate that BIM training requires more than the promotion of individual training. Promoting continuous learning at work is necessary to encourage people's engagement in the change.

### *2.2. Zone of Proximal Development and Collaborative Learning*

Vygotsky [10] introduced the concept of Zone of Proximal Development (ZPD), which recognises the interrelationship between learning and development, and proposes the distinction between actual and potential levels of development of an individual. The actual level of development is related to an individual's ability to solve a particular problem independently, while the level of potential development occurs when the individual receives some level of support to solve a problem. Therefore, the ZPD is the difference between the level of actual and potential development, whose evolution occurs with the appropriation of knowledge obtained under the guidance of people with advanced knowledge of the problem and with the collaboration of more knowledgeable partners [10].

Miranda Correia and Infante-Malachias [11] used the ZPD to identify three types of collaborative interactions through power asymmetry between teacher and student. In the context of our work, the teacher is replaced by the Leader of the collaborative work process and student(s) by a subordinate(s) (Figure 1), where (a) is a vertical and traditional collaboration between Leader and subordinate with a high degree of power asymmetry, (b) is a horizontal collaboration between subordinates with low power asymmetry and (c) is a diagonal collaboration with moderate power asymmetry.

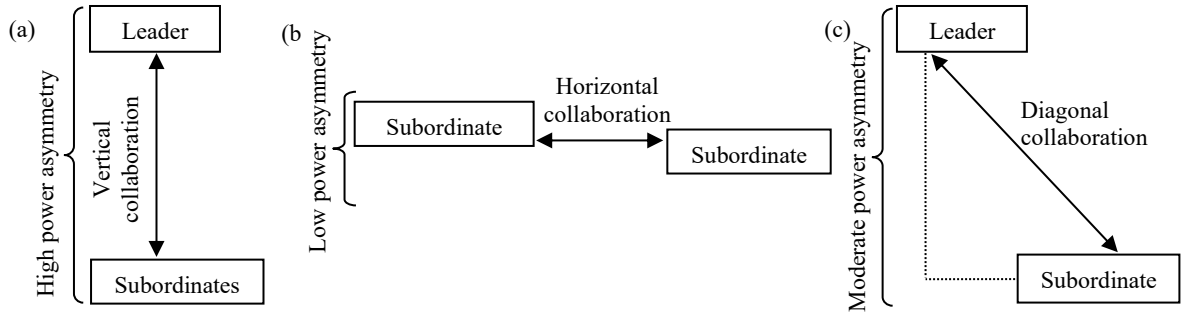


**Figure 1**. Power asymmetry in the learning process, where (a) is a traditional process (b) and (c) are collaborative processes (adapted from [11], p. 6).

A characteristic of Collaborative Learning is to promote the individual's engagement in the pedagogical process [10]. Thus, the collaboration concepts [11] are instrumental in analysing a real case and thus understanding how Collaborative Learning can be used in a real context of BIM implementation in a micro-enterprise (less than five employees) architectural design company.

## 3. Research Methodology

This research was developed as Documental Research (DR) [12], analysing e-mail records of a micro-enterprise architectural design company during the BIM implementation process. DR is a methodological approach based on archival methods [13], which involve activities of collection, preservation and cataloguing of documents, to guarantee the quality of scientific analysis. In this sense, Content Analysis was used as a quantitative approach associated with qualitative analysis care, taking into consideration the subjectivity of the analyst's interpretation of the content [14].

In Content Analysis, coding and categorisation aim to measure phenomena from a set of coherent theories [14]. Thus, they allow the transition between the content manifested in the text, of less abstraction, and the latent content interpreted by the researcher, of greater abstraction [15,16] related to the research problem.

Thus, coding and categorisation consist of a complex process. Both Bengtsson [15] and Erlingsson and Brysiewic [16] suggested using the collaboration of other analysts during the analysis process. Peer validation in research allows for reducing preconceptions and bias to achieve the necessary reliability for qualitative research.

The Content Analysis performed on the e-mails exchanged between the participants of a BIM implementation process from 2010 to 2015 was carried out in the following steps, as illustrated in Figure 2. Step 1 involved the import and coding tests with NVivo®[1]. Step 2 provided an overview of the content, allowing the definition of the general analysis strategy in step 3. Step 4 was the longest, with pre-coding, validation with other researchers and final Content Analysis. Finally, step 5 formalised the results presented in this work.

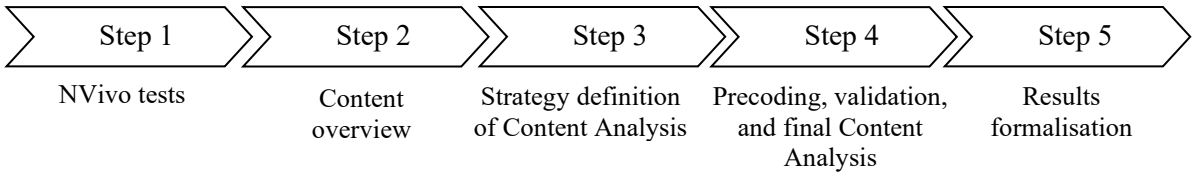


**Figure 2**. Content analysis steps

[1] NVivo® is a trademark of QSR International that is also the name of a data analysis software.

### *3.1. Context and corpus descriptions*

The BIM implementation at Company A took place from mid-2010 to the end of 2015. During this period, there was an exchange of e-mails received by the business leader[2] from the design development team. This set of e-mails was treated as the corpus and the messages as the document research analysis units. Furthermore, the set of e-mails was divided into two periods, from 2010 to mid-2012 and from mid-2012 to 2015.

Until June 2012, the team sent e-mails to the Leader on demand from those involved, unintentionally and unplanned. After mid-2012, it was instituted the creation of a "journal" by design team that had to be sent to Leader. The journal was intended to be prepared at the end of each day, which initially served to report the development of activities. However, the journal soon became didactic, as it was used to answer doubts or even establish a debate about specific points of technology and processes involved in BIM implementation. In addition, as some of the team members gained more experience, they shared with the Leader the responsibility of guiding others with less experience in the company.

In the period from 2010 to 2015, the team had a total of 21 professionals, in addition to the Leader and partner-owner of Company A. They developed non-structural masonry design for production, drywall design for production, architectural detailing, conceptualisation analysis, structure and facilities modelling and spatial compatibility between disciplines for a total of 71 large projects using BIM.

Some professionals worked in more than one function, developing their competencies. The functions performed were: (1) intern, (2) designer, (3) architect and (4) design coordinator. As an intern, the professional evolved in up to three levels, while the others were at a single level. The total number of functions performed was 34 during the BIM implementation period. Only the professionals did not register the logbook in six functions of this total. The evolution of professionals is shown in Figure 3. The graph also includes training the team by instructors hired for specific internal training actions, which were coded with In1 to In5. L1 is the Leader, who was also a founding partner of the company and therefore remained throughout the period from 2010 to 2015.

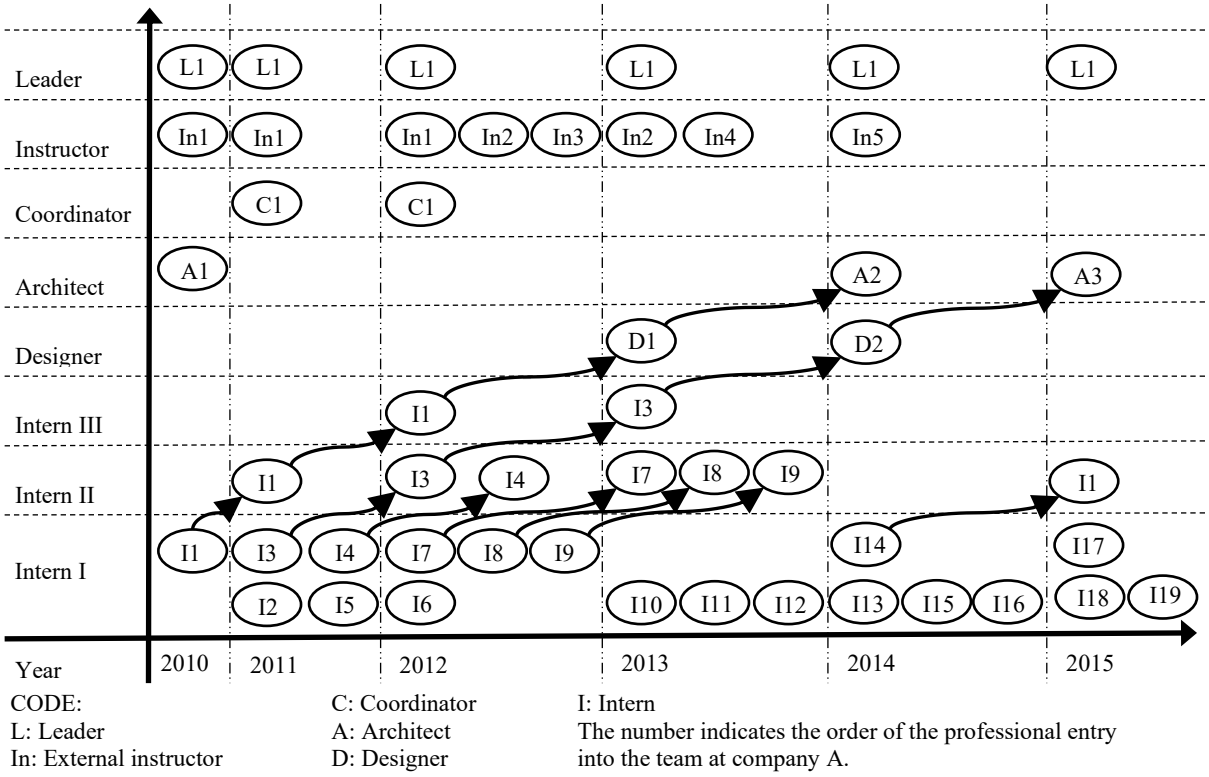


**Figure 3**. Evolution of professionals involved in BIM implementation from 2010 to 2015.

[2] The business leader was also the Main Analyst in our research.

## 4. Findings and Discussion

### *4.1. Preparation of content analysis and pre-coding*

The content analysis was developed in five steps, as shown in Figure 2. The analysis preparation involved steps 1, 2 and 3, respectively, NVivo® tests, content overview and content analysis strategy definition. The first stage, specifically, allowed the evaluation of the impact of the amount of data for selecting relevant data related to the research problem and definition of codes and themes compared to the literature.

In this pre-coding step conducted by Main Analyst, the total number of e-mails collected was 2999, referring to the study period. In this way, 448 of them were coded using NVivo® 12. The coded items were grouped into the categories "diagonal collaboration", "horizontal collaboration", and "vertical collaboration", according to the asymmetry of power in the learning process. Furthermore, "individual action" was added, which included "self-analysis of the work in progress" and personal expression of enthusiasm.

At the first step, it was possible to observe that more than half of the e-mails (249 out of 448) were simple descriptions of the activities, revealing the predominant relationship of vertical collaboration. Some e-mails from L1 were to draw the attention of a subordinate to the objectives of preparing the journal, especially at the beginning of the implementation of this procedure in the company. L1's guidance is highlighted, saying to subordinates that "this practice will help you to reflect on your tasks... how about trying to practice this?"

After this first data analysis, with the initial categorisation, the next step involved the content analysis by two other researchers to validate the results.

### *4.2. Content analysis validation*

The validation procedure with other researchers allowed us to guarantee the reliability of the results, introducing multiple perspectives to the analysis. In this sense, two other researchers with the formation in areas that are part of the content analysis context of Company A were invited. Moreover, given that the theme of this research was centered on BIM, focusing on learning at work, it was considered essential to complete content analysis with the knowledge of two other researchers in teaching-learning and organizational management.

After the first step of testing by the Main Analyst, the definitive content analysis was fulfilled. The following procedure was the identification of the registration units through automatic querying of the frequency of words in NVivo®. The automatic query generated a list of 1000 most frequent words, with their respective count. In the initial validation phase, the grouping of categories generated four categories: (1) vertical collaboration, (2) horizontal collaboration, (3) diagonal collaboration and (4) individual action. The categories were generated from the manual reading of the frequency of words, aligned with theoretical fundamentals from the study of Miranda Correia and Infante-Malachias [11].

The subcategories included in the vertical collaboration category involved the hierarchical relationship between the Leader and the subordinates. In this situation, the messages were characterised by passive postures, a simple description of the activities, comments from the Leader to the team member and general guidelines on the management of activities, translating into a typically "top-down" relationship. In horizontal collaboration, the relationship between those involved in the messages was between professionals at the same level or from one more experienced to another less experienced in a learning process. In this category, were also included messages that evidenced teamwork or tasks passed among those involved in equal or similar levels of knowledge. In diagonal collaboration, the messages involved the Leader in a general condition of demand from the subordinate. These also included situations in which the led person passed a task to the Leader, realising that this would be the person capable of developing the activity. Finally, individual actions were those in which it was possible to perceive evidence of active learning in isolation. For example, the professional showed awareness of what he (she) was learning, and this caused him great satisfaction, and he (she) was encouraged to

express him(her)self on this subject. These messages were classified under the category of "enthusiasm for learning".

There were differences in the categorisation of content, as shown in Table 1, and it is possible to observe that the percentages in some cases were closer between the Main Analyst and the 2nd. Analyst. For example, the Main Analyst tended to consider most of the content under the theme of "vertical collaboration" (56.3%). This interpretation was close to 2nd Analyst (51.4%), while 1st Analyst identified 29.4%. However, in the "diagonal collaboration" category, there was a significant divergence in the classifications between the two analysts (1st and 2nd) and the Main Analyst. 1st. Analyst interpreted that 27.3% of the content referred to diagonal collaboration, while 2nd. Analyst classified 17.9% and Main Analyst 6.5% for the same category.

Also, 1st Analyst did not identify any message regarding "peer trainee guidance" during the validation process and understood that horizontal collaboration is always "skilled-for-beginner guidance". So, the analysts come in consensus to include categorised messages in "per trainee guidance" into "guidance from more experienced to less experienced.

In the "horizontal collaboration" category, for the Main Analyst and 1st Analyst, there was a similar distribution in the total of 20.3% and 22.3%, respectively, different from 2nd Analyst, which categorised almost 14.9% under this theme. A different situation occurred in the "individual action" category, in which the Main Analyst categorised 17.0%, 1st Analyst 26% and 2nd Analyst 15.8%. Finally, 2nd Analyst, during the analysis process, questioned the category "use of advanced concepts in Revit". Due to ambiguities and the lack of a category to classify issues related to the use of the tool, the e-mails in this category were included in "Proactivity".

**Table 1** – Comparison between the content analysis from the analysts

| Themes | Categories | Main Analyst | | 1st Analyst | | 2nd Analyst | |
|---|---|---|---|---|---|---|---|
| Individual action | Self-critical analysis of work in progress | 49 | 10,9% | 132 | 10,5% | 63 | 7,6% |
| | Enthusiasm for learning | 8 | 1,8% | 69 | 5,5% | 13 | 1,6% |
| | Proactivity | 19 | 4,2% | 60 | 4,8% | 56 | 6,7% |
| | Subtotal | 76 | 17,0% | 261 | 20,7% | 132 | 15,8% |
| Diagonal collaboration | Comment on whether having difficulties | 10 | 2,2% | 268 | 21,3% | 112 | 13,4% |
| | Leader orientation on demand from the subordinate | 17 | 3,8% | 50 | 4,0% | 31 | 3,7% |
| | Task directed at the leader | 2 | 0,4% | 26 | 2,1% | 6 | 0,7% |
| | Subtotal | 29 | 6,5% | 344 | 27,3% | 149 | 17,9% |
| Horizontal collaboration | Guidance from more experienced to less experienced | 43 | 9,6% | 191 | 15,2% | 99 | 11,9% |
| | Peer task | 7 | 1,6% | 14 | 1,1% | 20 | 2,4% |
| | Teamwork | 41 | 9,2% | 79 | 6,3% | 5 | 0,6% |
| | Subtotal | 91 | 20,3% | 284 | 22,6% | 124 | 14,9% |
| Vertical collaboration | Learning about activities management | 1 | 0,2% | 1 | 0,1% | 6 | 0,7% |
| | Comment from leader to team member | 2 | 0,4% | 36 | 2,9% | 21 | 2,5% |
| | Simple description of activities | 249 | 55,6% | 315 | 25,0% | 368 | 44,2% |
| | Others | 0 | 0,0% | 18 | 1,4% | 33 | 4,0% |
| | Subtotal | 252 | 56,3% | 370 | 29,4% | 428 | 51,4% |
| TOTAL | | 448 | 100% | 1259 | 100% | 833 | 100% |

After these classification adjustments and the critical analysis of the analysts, the content analysis was discussed, allowing the identification of elements that generated collaborative and active learning during the BIM implementation at Company A.

### *4.3. Discussion: learning as a collective process*

Company A can be considered to have fully implemented BIM due to training the team over the period 2010-2015 through Collaborative Learning. One of the last projects of the analysed period, in 2015, was developed collaboratively with other discipline design companies within the concept of model federation [17]. However, internally within Company A, the central modelling feature has been used since the projects in 2012.

The e-mails analysis that the team exchanged over the period 2012 to 2015, under the encouragement of the process leader, described the problems faced in the work development process, accompanied by descriptions of how with the help of the other members. Collaboratively, each participant was able to overcome the difficulties. Moreover, problem-solving was accompanied by expressions of enthusiasm for learning, which analysts understood as a source of evidence of the connection with Vygotsky's theory of learning [10].

As the team grew and some members advanced in knowledge, this leadership effort was shared with more experienced professionals. An example is the record of one of the junior architects (A3), already at a more advanced level in appropriating knowledge about BIM, who guided an intern (I17) on the journal function for learning. In this e-mail, A3 addresses one of the interns, in response to the journal, instructing him or her to "better describe his/her tasks in the activity diary". A3 also reinforced that the intern should "[C]consider the activity diary as the synthesis of their learning and not just the monitoring of tasks."

This guidance appears in the records classified as "Horizontal collaboration" in the "Orientation from more experienced to less experienced" subcategory, which was 49 out of a total of 448 records. These "horizontal collaboration" records of the type "Orientation from more experienced to less experienced" were obtained in two ways: more experienced and less experienced journals. Of this total of 49 messages, two referred to the type of guidance presented in the example above, in which the more experienced directly guides the less experienced via the journal e-mail. Another ten messages are from the more experienced ones reporting to L1 guidance questions to the less experienced, and the rest, 23, were messages from the less experienced ones reporting guidance received. When a critical view accompanies these descriptions, the messages were classified as "Self-critical analysis of work in progress".

It was also noticeable that the team development, reflected in the evolution from intern I1 to designer D1 and later to Architect A2 and from I3 to D2 and A3, increased team engagement and messages coded as "Self-critical analysis of work in progress". Besides, with a predominance of coding for "Self-critical analysis of work in progress" after 2013, it was possible to observe that new members were encouraged to be critical and self-critical by older members.

Also, related to the evidence on collective learning, leadership participation played an important role in collaboration among team members, seeking to reduce competition and encouraging cooperation as a success factor for learning and work results. The word "guidance" – very common among both the more experienced and the less experienced, also observed by one of the analysts – conveys an intrinsic value in the activity related to support in the learning process, while this was an orientation given by the Leader to the team members.

Despite the quantitative effort undertaken in the content analysis, the qualitative aspects made it possible to understand the evolution of the team training, that is, its development. Content analysis brought evidence of Collaborative Learning in the training process for BIM implementation, which was combined with an instructional basis through training to disseminate knowledge during the activities. This information does not appear directly from the Content Analysis, but the context described about Company A and the general strategy adopted for the team training.

Each analyst contributed with his/her view to content analysis. For example, some interpretations were justified by 1st Analyst because the learning process is inherently collective, which is comprehended by the ZPD concept. On one side, 1st Analyst contributed to the theoretical interpretation of cognitive aspects of learning and how this revealed itself in evidence of Collaborative Learning. On the other side, 2nd Analyst brought the organisational perception of the role of leadership in BIM training, reflecting on the relationship between specific words and functional positioning in the business. 2nd Analyst highlighted the more frequent use of certain words by architect-coordinators, those with more experience and in a higher hierarchical position, such as Architect. Words like "executed" and "problem" were among the e-mails from interns.

In the discussions between the analysts, these differences could be related to each other's biases. For example, both the Main Analyst and 2nd Analyst are professionals in architecture, while 1st Analyst is in pedagogy. In this case, the contribution of 1st Analyst in the perception of evidence of Collaborative Learning, which supported this discussion, was considered relevant.

## 5. Conclusions and Further Research

The intrinsic collective process characterises collaborative learning in developing higher mental functions [10]. In the dynamic between learning and development, the opportunity for the educator or, in the case of this research, the team leader in promoting the introduction of new knowledge resides. With the growth of the team and delegation of the role of coordination and instruction, the introduction of knowledge could be observed at an intermediate stage, in which the Leader now assumes a passive attitude of being informed and approving solutions and process improvement.

Another view of these results provided evidence on the existence of power asymmetry between the participants that were not explicit in the team formal organisational, leading to contexts of collaboration, sometimes supported by a partner of the same level, sometimes supported by the design leader or even a more experienced colleague [11]. However, future studies of field experiments are needed to better understand collaborative learning dynamics in BIM implementation and whether this process could be maintained organisationally, especially in small design firms.

## Acknowledgments

National Council for Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq), Brazil [Grant No. 308379/2021-7], and São Paulo Research Foundation (FAPESP), Brazil [Grant No. 2020/15909-8].

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